Design of a Small Detachable Backhoe

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Abstract

Charles Machine Works, Inc. (CMW) produces a wide range of underground and earthmoving equipment. Over the past five years, the company has developed a new line of products known as compact utility machines. The compact utility industry is currently occupied by several manufacturers, including CMW. Compact utility machines are typically compact loader type units that mate to a multitude of attachments allowing them to accomplish many different tasks. Since their inception, CMW has been working to create a product line of attachments for the machines made at the CMW plant in Perry, Oklahoma. Engineering Specialties was approached and asked to design a small backhoe for a CMW manufactured compact utility machine. In addition to upholding the same traditions of quality and value as other CMW machines, the backhoe also had to meet a strict list of design criteria to comply with both CMW and industry standards. Through field research and design, Engineering Specialties was able to produce a successful working prototype which is continuing to be used even today. Through our design, testing, and construction, our team has successfully met or surpassed the design criteria set forth by our sponsors.

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Introduction

Charles Machine Works, Inc. (CMW) is a manufacturing company that builds construction equipment in Perry, Oklahoma. Over the past 50 years, CMW has become synonymous with building the highest quality underground construction equipment in the world. They began in the late 1940s with a mechanical powered trencher that owner and founder Ed Malzahn built in his father's machine shop (Figure 1).

Figure 1: Ed Malzahn and his revolutionary trencher.

This one machine has evolved into what the world now knows today as Ditch Witch®. For the past 50 years, Ditch Witch has expanded its lineup to include horizontal boring machines, vibratory plows, and more recently, compact utility machines.

Ditch Witch is an industry leader in the trenching market, introducing the first mechanical trencher in 1949, and has continued to be on the forefront with the latest innovative technology ever since. Over the years, their product line has expanded to include various size trenchers as well as vibratory plows and backhoes. In the late 1980s, they began to explore the emerging horizontal boring industry and eventually

produced an entire line of directional boring machines. More recently, Ditch Witch has decided to expand its lineup and branch out into the compact utility market.

The compact utility market segment has exploded in the last few years and is currently the fastest growing segment of the construction equipment industry. Ditch Witch manufactures multiple models that fall into this category. The vehicles have the capability of attaching over 70 different tools to the front, making these some of the most versatile machines on earth. Currently, this market produces annual net sales of approximately six billion dollars worldwide, making it an excellent venture for any company already involved in the construction industry. Unfortunately, several other companies, both large and small have begun to manufacture similar machines and attachments.

Problem Statement

Our team has accepted the challenge to design a small, detachable backhoe for the SK500 compact utility machine. Currently, Ditch Witch offers a backhoe for this model, but it is outsourced from another company. The purchased backhoe does not satisfy many of the design criteria desired by Ditch Witch. Therefore, Ditch Witch has decided it would be beneficial to their company if they were to design and build a backhoe of their own. This would allow them to offer some additional features as well as help to increase the overall profit margin on the SK500. The backhoe designed by our team will fit the SK500 compact utility machine and adhere to all of the design criteria set forth by Ditch Witch.

Statement of Work

For our design project, the team will be designing a small, detachable backhoe for a compact utility unit manufactured by Charles Machine Works, Inc. in Perry, Oklahoma. Charles Machine Works, also known as Ditch Witch, is one of the leading manufacturers of trenching and underground excavating equipment in the world. Over the past 50 years, the compact utility market segment has grown into a six billion dollar worldwide market. Ditch Witch has released two hugely popular compact utility vehicles: the SK300 and the SK500. These small vehicles can utilize over 70 different attachments, making them possibly two of the most versatile tools to enter the market in the last 30 years. Currently, many of the attachments for the SK's are purchased from outside vendors. However, Ditch Witch is now interested in producing more of these attachments "in house." This offers multiple benefits including the knowledge that the equipment they sell is completely compatible with their machines and an increased profit margin. One such attachment is the mini backhoe.

After meeting with the design engineers from Ditch Witch, the team set forth some of the criteria this unit was expected to meet. First of all, it would have to attach to the SK500 unit via the quick-attach plate in the front of the machine. Our team would also have to assure the overall width of the backhoe did not exceed 36 inches, making even the smallest spaces accessible. In addition, the backhoe would also have to dig to a depth of at least 78 inches and have an overall weight not exceeding that of the current purchased unit (780 lbs.). The backhoe must incorporate some sort of mechanism to "lockout" the use of the tilt function on the attachment plate. Users will often rotate the attachment plate to reposition the backhoe to get a deeper or larger hole.

This may be unsafe for the user and make the machine unstable. The unit would be powered by the attachment hydraulic circuit on the machine, include safety kill switches, and have all wires and hoses easily disconnectable at the mount plate. While accomplishing these things, it would also need to outperform the current model in some areas.

Some of the features required to exceed those of the present model include allowing the hood to open while the unit is attached as well as being easy and quick to disconnect (less than 5 minutes). Ditch Witch also desires to have some type of stabilizers to keep the SK balanced and steady during normal operation. The team looked at multiple approaches to this problem and agreed that further testing would help confirm solutions. Most conventional backhoes use a pair of pads that raise and lower hydraulically to keep the unit sturdy. However, one of the prototypes had a large blade mounted below the pivot post on the backhoe which doubled as both a brace to hold the machine and a backfill blade to fill in the hole once the digging was complete (Figure 2).

Figure 2: Backfill blade built in to main frame of backhoe.

In addition, the backhoe would also be composed of as many “in-system” Ditch Witch parts as possible (cylinders, valves, bushings, etc…). This would not only make it easier to manufacture but cheaper as there would be no need for additional tooling. The design should also have a light kit included. Light kits have become much more commonplace on backhoes as they are used in residential areas or near streets where high visibility is imperative.

Patent & Market Research

Patent Research

To begin our research into backhoe design, the team did preliminary research into backhoe and small digging attachment designs. Many of the backhoe patents found were outdated. Most of the patents having to do with the backhoe design or design of the hydraulic systems were issued back in the 1960s and 1970s, making them obsolete. As the group began to search the internet, the absence of applicable patents became even more evident as the team found several different manufacturers of both small and detachable backhoes for use on small tractors, compact utilities, and other machines.

Market Research

Market research revealed that there are numerous compact utility vehicles on the market. The biggest competitors in this segment are Toro and Bobcat. Toro is the predominant competitive machine in this class. Toro took advantage of its large presence in the lawn and garden market to introduce a handy utility machine for both home owners and landscapers. The machine features several different attachments, including a backhoe made by Toro. The biggest difference between the Toro and Ditch

Witch machines is the use of rubber tires on the smaller Toros (Figure 3) versus tracks on the SK.

Figure 3: Toro Dingo compact utility unit.

The backhoe currently offered by Toro is considered a light duty machine, with less potential in the more rugged construction industry. However, it provides a light and effective choice for customers needing to do small excavation jobs.

The Bobcat machine has similar roots to the SK. Bobcat has made a name for itself in the construction industry with its rugged line of skid loaders. Like Ditch Witch, Bobcat has ventured into other markets including the compact utility segment (Figure 4).

Figure 4: Bobcat compact utility loader with pallet fork attachment.

While Bobcat does not currently offer a backhoe option with their compact utility machine, consumers can still purchase aftermarket backhoes for the Bobcat machines.

Ditch Witch is looking to take advantage of its already established customer base in the small to mid-range construction equipment much like Toro and Bobcat did in their respective industries.

Engineering Specifications

Ditch Witch expressed a set of criteria the machine must satisfy. Currently, Ditch Witch purchases a backhoe from another OEM vendor, BradCo.

Figure 5: Ditch Witch SK500 with BradCo backhoe attachment.

While robust and effective, the BradCo backhoe lacks many of the refinements and features Ditch Witch desired. Below is a list of specifications for the backhoe attachment set forth by Ditch Witch.

- Attach with the Ditch Witch quick couple on the SK 500.
- No wider than 36".
- Incorporate some kind of stabilizing system.
- Use as many "in-system" components as possible.
- Lock on tilt.
- Must have a remote kill switch at operator's seat. (Ditch Witch Standard)
- Dig a 6' 6" deep hole.
- Ability to open the hood fully on the SK 500 while backhoe is attached.

Design Concepts

The team has formed some feasible design concepts based on limited testing. Due to an extremely wet weather pattern, the team has only been able to test the designs once. During that period, valuable insight was gained on how the prototypes work as well as what features helped or hindered the digging process. Our team was unable to

do any further testing with the machines to become more familiar with them and aid in our concept development.

During the testing, the machine's instability was immediately apparent. Based on observations, this was a result of several aspects of the design. One contributing factor was the size of the bucket on the machine. The prototype utilized a 12-inch bucket, which was later found to be somewhat excessive for this particular application. The larger bucket provided a much larger "grab area" as the bucket tried to dig into the soil. This larger area resulted in the machine being moved around excessively (Figure 6).

Figure 6: Track skid marks left after digging with prototype machine.

Our team believes the use of a smaller bucket could greatly improve not only the stability of the machine, but also the overall performance. This prototype utilized the backfill blade in the front as its stabilizer. While the backfill blade is a welcome addition to add to the overall versatility of the machine, it does not do a good job of securing the machine. This is even more evident when digging in already disturbed soil, as seen in Figure 6. It was concluded that a larger pad between the attachment frame and the backfill blade would be very beneficial. This pad would not only serve to strengthen the design, it would more importantly provide a much more solid footing for the machine during operation. Since the SK500 is not excessively heavy, no form

of stabilizer can be expected to keep the machine completely anchored. However, our group concludes that the pad and blade combination would provide an adequate anchor without disturbing the soil.

Another area needing to be addressed in this design is the hydraulic control valve. While the valve used on the prototype was adequate, our group feels the control characteristics could be improved to help bolster the overall efficiency of operation. The prototype had a reduction orifice in one of the ports. Unfortunately, the orifice was in the wrong port, and it became immediately evident how much this affected the handling characteristics of the machine.

Design Concept 1

The first design concept considered is similar to a design already incorporated at Ditch Witch on other larger scale backhoes. To aid in their digging ability, Ditch Witch currently uses a compound arm on some of the larger machines. The setup moves the pivot point of the backhoe allowing the rotation of the backhoe to swing approximately 270 degrees. The whole design will be scaled down to fit the smaller backhoe (Figure7).

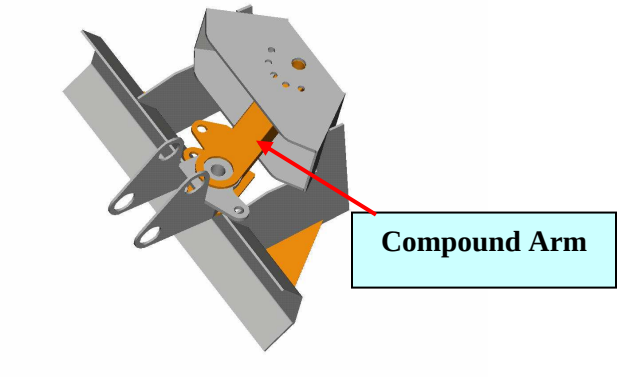


Figure 7: Top view of compound arm design.

The biggest advantage offered by this setup is the ability to make the backhoe unit offset. The user is able to move the pivot point of the backhoe across the front of the machine. This feature is especially useful in residential or small areas that require the machine to dig next to an obstacle such as a fence or structure. In addition, many of the components needed to construct such a design are in-system parts.

With the compound arm design, the overall center of gravity of the machine would be shifted in front of the main backhoe frame. Therefore, the machine would tend to be heavier in the front. This will increase down force on the stabilizers, making the machine more stable and much safer.

Design Concept 2

The second design concept is also used in several applications at Ditch Witch on larger scale backhoes. This design incorporates a single, double-ended cylinder and chain links to rotate the boom of the backhoe (Figure 8).

Figure 8: Double-ended cylinder and chain rotation system.

The design is compact and effective at rotating the boom in a confined space. However, the double-ended cylinder is rather expensive and there have been some concerns with chain tension in the past. Also, with this design the pivot is stationary and cannot be offset as in design concept one. One challenge has been maintaining the proper tension on the chains. On some of the larger backhoes, Ditch Witch has encountered problems with slack in the chain at different points in the rotation because the radius of the pivot is not constant. The pivot is a cast part keeping the dimensions exact can be a challenge. On larger models, a small percent change in dimensions can result in big changes in the radius causing slack in the chains. Users try to tighten the chain to take out the slack and over-stretch the chain as it runs through the full turn arc. This small backhoe requires a much smaller pivot, improving manufacturing tolerances. As a result, this problem becomes insignificant.

The booms are redesigned to reduce the overall weight of the machine. The geometry and location of pivot and hinge points will remain approximately the same, keeping the digging depths and overall functionality of the machine as similar as possible to the other prototypes.

The main frame is the same as the one used on the prototype machines. Not only does this frame mate well to the pivot and backfill blade, it is also meets the 36-inch width specification.

Design Concept 3

The third concept is a modified version of a concept already built by Ditch Witch. This design is similar to design concept one (Figure 9).

Figure 9: First prototype tested at Ditch Witch.

The goal of this design is to construct a unit similar to the existing concept with a few additional features to help improve the overall performance of the machine. The most significant addition will be stabilizers. The stabilizers are similar to the outrigger design that larger loader-backhoes incorporate. In addition, the boom and dipper cylinders are resized in an effort to be more efficient as well as save on the overall weight. The design team explored the possibility of modifying some of the parts already used on current Ditch Witch products to make them more cost effective and reduce the overall weight of the machine. This design is based off of the concept previously built by Ditch Witch the Research and Development Team. During field testing, this design (Figure 10) proved to be very competitive with the BradCo backhoe currently being purchased by Ditch Witch.

Figure 10: Ditch Witch Concept 1 small detachable backhoe.

Final Design Selection

After consulting with engineers and product managers at Ditch Witch, our team selected a final design and gained a better understanding of what features the product needed to include. After looking at the three proposals set forth by our team, Ditch Witch concluded it would be best to pursue Design concept three.

The company currently sells approximately 20 units per year for the small detachable backhoe. Using as many in-system parts as possible would allow Ditch Witch to place the design on the market sooner, without requiring extensive field tests to prove the product's durability. The use of common parts also helps keep overall manufacturing costs down, increasing profit margins.

In addition to the cost savings, product managers for Ditch Witch also felt this prototype had the best market potential. In designing a replacement for the BradCo backhoe, our team was going to be competing directly against that backhoe. Therefore, our prototype had to include almost every feature of competitor's machines in an effort to prove our ability to not only compete with but out-perform their machines. Design

Concept three offered the best combination of cost effectiveness, manufacturability, and performance.

Final Design Implementation

The final design is comprised of a combination of newly designed, in system, and altered in system components (Figure 11).

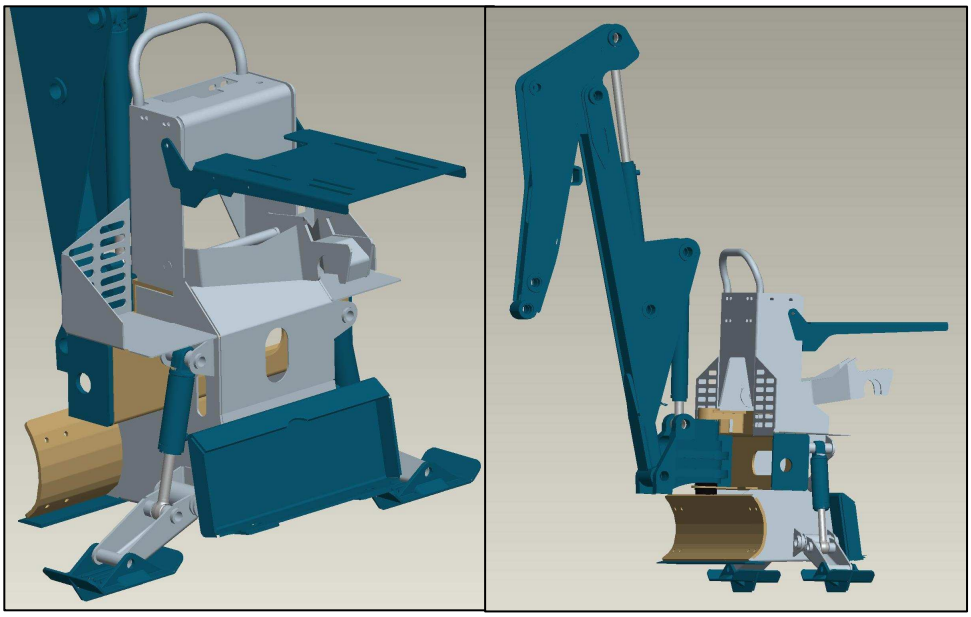


Figure 11: CAD drawings of backhoe.

The components highlighted in blue represent all the components which are currently in system. The tan components represent current in system components which have been altered. Finally, the gray components are the newly fabricated components for our design.

Frame

The frame is made up of three main components: pivot cylinder mount, main frame, and tilt lock. The pivot cylinder mount serves as a cross member in the frame as

well as an attach point for the cast pivot. The cylinder mount weldment is composed of eight parts currently used as an assembly on the HT25 model backhoe at Ditch Witch. The weldment consists of two bosses welded to a flat plate and a bent C-channel plate. Two gussets are used to support the top mount for the pivot while two more plates are welded to each end of the C-channel to help secure the double-ended cylinder. The end plates are made from 0.50 in. thick 1018 CR steel while the gussets, top plate, and C-channel are made from 0.188 in. 1018 CR steel. All of these parts were made from thicknesses similar to in system parts.

The second frame component is the main frame itself. The main frame is a single piece of 0.188 in. thick 1018 CR steel with five bends to form the box of the frame small gussets on the bottom to support the quick-attach plate. The frame is cut to accommodate the pivot cylinder housing and backfill blade on the front as well as the quick-attach plate on the rear. It features holes in the top of the frame which are used to hold the hydraulic control valve in place (Figure 12).

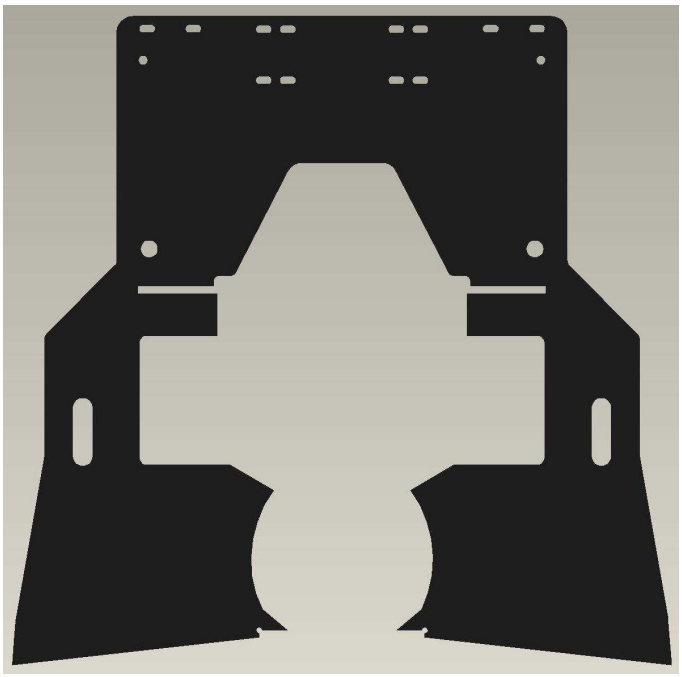


Figure 12: Flat pattern layout of main frame with holes at top for valve attachment.

Besides the two main frame components, the design also uses a kick plate installed in the rear of the main frame to prevent the operator from being exposed to hydraulic lines as well as provide structural integrity for the frame.

Figure 13: Top link for quick attach system.

The final frame component is the top link for the quick-attach system (Figure 13). The purpose of the top link is to prevent the operator from altering the pitch of the backhoe once it is attached to the machine. The latch is made of two 0.25 in. 1018 CR steel plates. These plates pivot on the main frame, allowing for easy raising and lowering of the link to attach or remove the backhoe from the SK unit. In addition, the link utilizes small tabs on the end to help hold the seat in the raised position for easy access under the SK hood. Should the operator choose to reapply the link and still leave the seat in the upright position, the seat can also be secured with a secondary latch to prevent it from falling on the operator.

Stabilizers

The stabilizers for this machine use both new and existing parts. In an effort to keep the operator's station free from obstructions and keep the overall width of the machine less than 36 inches, the stabilizers were designed to be short and compact. The stabilizers are constructed out of a single plate of 0.188 in. 1018 CR steel which is then bent into a C-channel. The channel is welded to a machined boss at the pivoting end and controlled by a 2 in. bore, 1in. rod, 4 in. stroke cylinder. The pivot bosses and the cylinder mount bosses are parts Ditch Witch currently uses on other products. This design uses two independently controlled outrigger stabilizers. With independent controls, the operator may use them individually or not at all, depending on operating conditions. The stabilizers are less than 35 in. wide when in the up position and are hidden conveniently under the operator foot rests (Figure 14).

Figure 14: Stabilizer in folded up position inside the edge of the blade.

In the down position, the stabilizers have the ability to increase the base width of the machine to over 50 in. and can extend slightly over 2 in. below the bottom of the backhoe frame, making them effective in both hard packed and soft soil conditions. The stabilizers use large cast iron pads with lateral tabs on the bottom that help prevent front to back movement of the machine. In addition, the stabilizers are also strategically located at the rear of the backhoe frame in front of the loader quick-attach plate (Figure 15). Side to side movements in both the backhoe and the loader arms are eliminated.

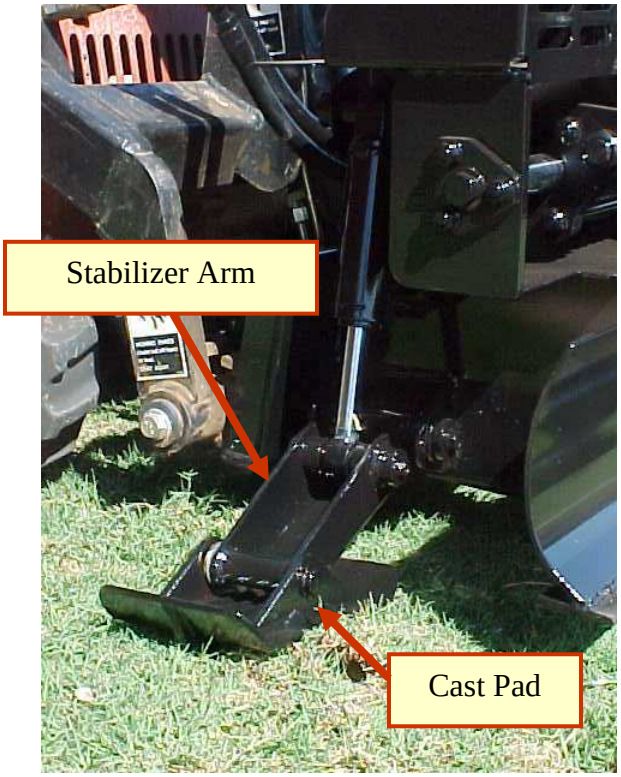


Figure 15: Stabilizer arm in down position.

Boom and Dipper

In the design of the boom and dipper for this machine, our team chose again to use as many current components as possible. The best choice for a boom and dipper is the combination currently used on the XT850 excavator-tool carrier. To improve the performance of the design and lower the overall weight, the team chose to replace the 2.5 in. bore, 1.5 in. rod cylinders with 2 in. bore, 1.25 in. rod cylinders. The cylinder switch required a change in bushing size in the boom and dipper to accommodate the cylinders. The change also yielded a weight savings of over 25 lbs. while still producing a breakout force (dipper) of 1,475 lbs.

Additional Features

In addition to the main backhoe components, the final design is also equipped with a backfill blade mounted on the front of the frame. Besides being a convenience on the jobsite, the blade also provides structural reinforcement for the frame and pivot while also serving as a sturdy base during machine operation. The blade is equipped with a cutting edge (Figure 16) that can be used to slice into the sod covered earth to clear a digging area.

Figure 16: Backfill blade with cutting edge.

It also provides a "glide" to keep the tip of the blade from biting in when trying to refill holes and scoop dirt from grass, driveways, or sidewalks.

Safety Features

As with all engineering designs, user safety is a paramount concern. Therefore, our team has incorporated several features which make the machine safer for the operator. Our design is short and compact with an overall operator seat height of 37 in. (compared to 46 in. on the BradCo design). The backhoe incorporates a safety kill

switch for the engine so the operator can shut the SK500 off while on the backhoe. The tilt lock also serves as a safety feature in that it does not allow the operator to tilt the attach plate of the SK500 forward or backward while operating the backhoe. Our design is equipped with large floorboards and foot guards (Figure 17) to keep the operators feet and legs protected from the stabilizer arms and the boom and dipper during operation.

Figure 17: Floorboard with front and side foot guard.

Our design also features a larger, high-back operator's seat, ensuring the operator is not only comfortable but stable during operation. Finally, the backhoe is also equipped with reflective decals, making it easily seen in both day and night. The final design can be seen in Figure 18.

Figure 18: Final backhoe design attached to SK500.

Testing Results

Once fabrication and assembly were completed, the backhoe was taken to the field and put through Ditch Witch's standard testing procedures. In addition to taking measurements for the overall dimensions and capabilities of the machine, Ditch Witch test personnel used the backhoe for an extended amount of time to see how well it performed in normal working conditions. The testing personnel experienced no major problems with the machine. Upon conclusion of the testing, the machine underwent a thorough inspection to check for any problems or failures that may have occurred. The only problems found consisted of one loose bolt and another loose nut. This problem

was easily remedied by installing Loctite ® on the threads of the bolts; a step that had been omitted during our initial assembly.

During some of the preliminary design team field testing, a slight problem with the stabilizer arms was detected. While digging with the machine, our team noticed the stabilizer arm moved back and forth on the pin connecting the pad to the stabilizer arm. In addition, the tabs at the end of the stabilizer were flexing under the heavy loads. To avert this occurrence, a piece of tubing was inserted between the stabilizer sides to prevent any flexing or bending at the tip of the stabilizer. While this alteration solved the problem, our team chose to redesign the stabilizer arms to include thicker material. The 0.188 in. steel lacked the necessary rigidity needed to prevent flexing under load. As a result, the stabilizers were remade from 0.25 in. steel which eliminated the flexing problem we detected in testing. The pivot boss attached to the rear of the stabilizer arm was also redesigned to save weight. In the end, the stabilizer assembly was approximately two lbs. lighter, while offering more strength and rigidity under loading conditions.

Further Recommendations

While the prototype performed well in the field, our team the professional testing personnel from Ditch Witch made comments on possible design refinements. Overall, testers felt the backhoe performed exceptionally well. Ditch Witch personnel were very impressed with the redesigned tilt lock mechanism which made it easier for the operator to not only attach the machine to the SK500, but also perform any maintenance on the SK500 while the backhoe was attached. Also, testers were pleased with the addition of

the stabilizers. They felt the stabilizers offered more stability for the backhoe during operation, especially in soft soils. The stabilizers also helped eliminate the side-to-side movements in the loader arms typical during backhoe operation.

One area of concern was the clevis mounts for the stabilizers and the stabilizer cylinders. Originally, these clevises were manufactured from 0.188 in. steel. While providing the necessary structural strength, our team felt that upgrading these pieces to 0.25 in. steel (similar to the upgrade on the stabilizer arms) would provide a more rigid mount and pivot point for the arms. Time constraints prevented the construction of another prototype unit. However, with the current design and these recommendations, Ditch Witch would easily be able to implement these upgrades when the machine undergoes the necessary pre-production process at the Ditch Witch plant.

The current hydraulic valve on the backhoe is another area where improvements could be made, not for performance, but for cost. The current valve is an in-system valve that Ditch Witch uses on another backhoe in production (A322). The valve is more than adequate for our design. However, Ditch Witch also uses another backhoe valve (A225) which would easily meet our requirements. Unlike the A322 valve, the A225 valve does not contain the additional two sections needed to operate the stabilizers. Initially, our team had planned to use a small solenoid-operated valve manufactured by Eaton Vickers. The Eaton Valve, combined with the A225 valve, would allow the unit to utilize a smaller main valve, saving weight and reducing the overall cost. However, due to supply problems, Ditch Witch was never able to obtain the valve to test on the backhoe. After discussing the issue with hydraulic systems designers at Ditch Witch,

they felt the valve would be available by mid-summer 2005, making this another viable alternative for Ditch Witch to consider in pre-production.

An area of considerable cost on the backhoe is the hydraulic components. The valve and cylinders are very expensive, but necessary components of this design. Ditch Witch currently manufactures all of its hydraulic cylinders in house making custom cylinders possible. While all of the cylinders on our machine are adequate, changes to the boom cylinder would improve the overall performance of the machine. The boom cylinder has a 16 in. stroke. Since our design utilizes a boom and dipper already in production, the location of bosses and pivots are already set. Therefore, the cylinders had to fit these pre-existing points. To keep the boom from lifting too high, the 16 in. stroke cylinder utilizes a stop to prevent the cylinder from fully contracting (Figure 19).

Figure 19: Cylinder stop preventing full retraction.

Ditch Witch does not make an 18 in. stroke cylinder with the correct bore and rod dimensions. However, since Ditch Witch makes its own cylinders, the possibility of making an 18 in. cylinder exists. By replacing the current 16 in. cylinder with an 18 in. cylinder, the need for the stop would be eliminated because of the longer retracted length of the 18 in. cylinder. The boom would be able to extend lower, increasing the digging depth of the machine by a few more inches.

Project Schedule

With the completion of our prototype, our team consulted project managers at Ditch Witch to understand what it actually takes to implement a product once the initial design work is complete and the first prototype has been built. Based on their input concerning such things as manufacturing, testing, component availability, and various other design factors, our team assembled a projected schedule for implementation of our design. Based on this schedule, our team feels the backhoe could be in production by July of 2006, with the earliest possible production date being January 2006. The full Gantt chart may be reviewed in Appendix A.

Project Budget – Cost Analysis

Early in the design process, our team assembled a projected budget and calculated the project cost to be approximately $2,800.00. Due to unexpected rises in both energy and steel costs, these figures were inaccurate and out of date by the time the prototype was in the production stages.

Upon completion of the prototype, our team assembled a final budget for the backhoe. The initial cost of the backhoe including all assembly labor, raw materials, and manufacturing costs was $4,017.09. After this cost was analyzed, the project was reassessed and areas were found in which the overall cost could be reduced. After consulting with designers from Ditch Witch as well as doing some additional research about available parts in-system, our team compiled multiple cost saving suggestions for the design. One of the biggest savings was the utilization of a different bucket. A ten inch bucket yields a cost savings of almost $140. In addition, the substitution of the main hydraulic control valve with another valve could also provide upwards of $100 in savings. Based on cost saving suggestions, our team was able to achieve a final cost of $3,603.09 (Figure 20).

Total – Fabricated Parts	$204.54
Total – In system Parts	$3,162.75
Total – Assembly Labor (est.)	$649.80
TOTAL INITIAL COST	***$4,017.09***
Total – Component Replacement Savings	$414.00
TOTAL FINAL COST	***$3,603.09***

Figure 20: Final cost table including assembly costs.

The final cost of the machine is slightly higher than what was expected when the project began. However, this was attributed to cost increases that took place during fabrication. Our backhoe design is competitively priced with the BradCo unit, with the BradCo being slightly less expensive at $3,125.25. Nevertheless, our team feels

customers will be more inclined to purchase the Ditch Witch machine based on all of the features and capabilities it offers which the BradCo does not (Figure 21). A complete list of parts from Ditch Witch used in this design (including the standard backhoe operator's manual) may be reviewed in Appendix B.

	Ditch Witch	BradCo.
Large Operator's Seat	**YES**	No
Backfill Blade	**YES**	No
Under 36" wide	**YES**	No
True quick attach	**YES**	No
Low Seat Height	**YES**	No

Figure 21: Ditch Witch vs. BradCo backhoe feature comparison.

Conclusion

Overall, our design team feels the objectives of the design proposal have been met. Ditch Witch asked our team to design a small detachable backhoe to not only compete with but out perform the current offering from BradCo. Our team has worked to create a competitive unit that offers many convenient and safe features to its users. While solving some of the existing problems such as width, machine serviceability, and attachment issues, our team also managed to incorporate additional features, such as the backfill blade, to increase the overall value of the machine to the customer. In addition, it is built with many of the proven components already in use on other Ditch Witch products, allowing it to be easily implemented at a very low cost with only a limited amount of field testing required. We feel we have gained valuable experience to be

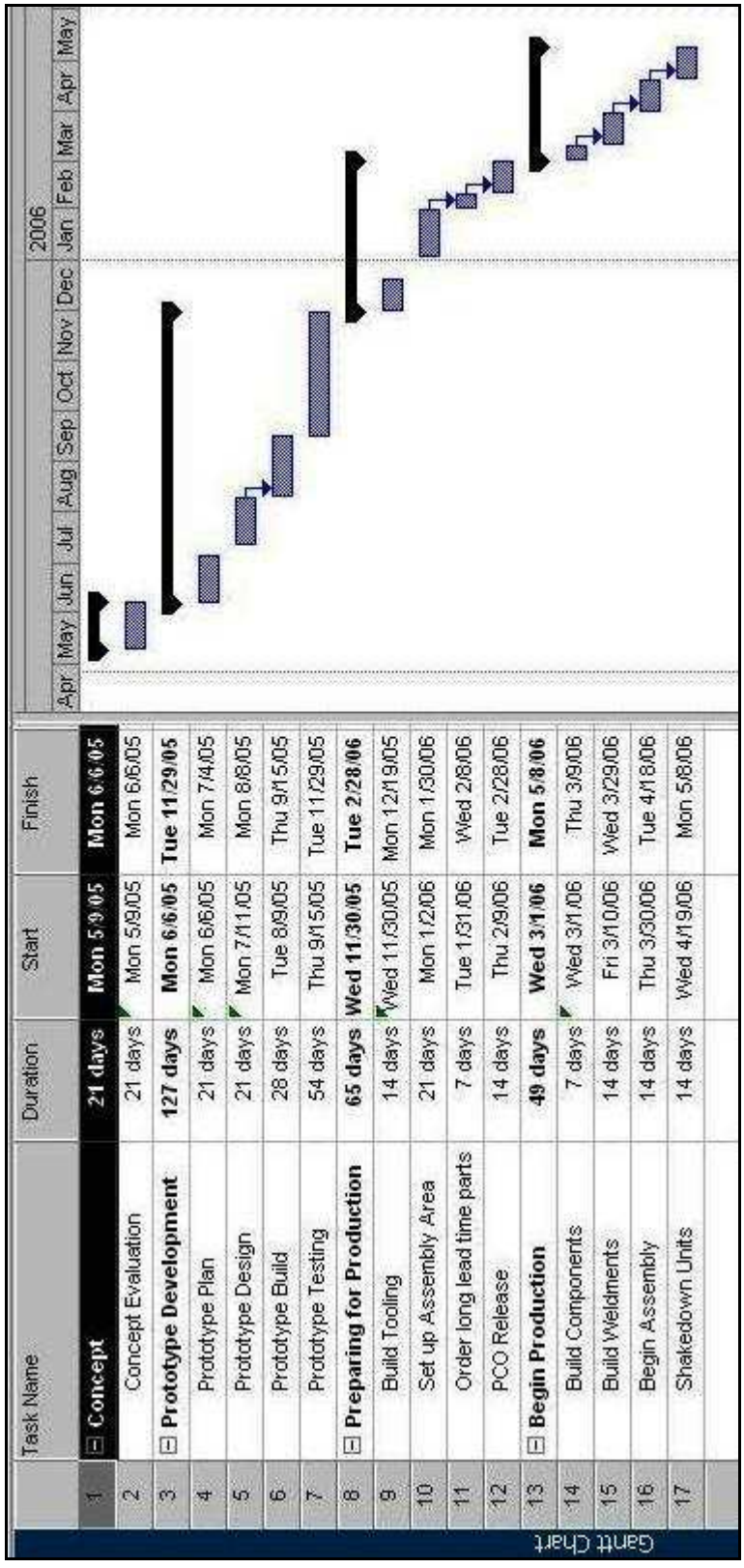
used later in our engineering careers. By working with the designers and engineers at Ditch Witch, our team was exposed to many different facets of the design process and given an overview of how a real-world company completes a design project from idea conception to finished product.

References

Shigley, J. E., Mischke, C. R., Budynas, R. G. *Mechanical Engineering Design.* New York, N.Y.: McGraw-Hill Company. 2004. 7th Edition.

Womack Machine Supply Co. Fluid Power & Automation Control Designer's Manual. Dallas, TX. 1999. 42nd Edition

Appendix A – Gantt Chart



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Appendix B – In system parts list

COSTING INDENTED EXPLOSION FOR 000000 4/14/2005

LEV	P/N	QTY	CD	COST	DESCRIPTION
	000000	1	0	$3,162.75	SPECIAL BOM
1	105-089	4	1	0.00	LOCKNUT (5/16-NC)
1	105-286	4	1	0.00	BOLT (3/8-NC X 1-3/4")
1	105-398	2	1	0.33	WASHER (1/2")
1	105-880	4	1	0.00	SHLD BLT (3/8" X 2", 5/16-NC)
1	106-098	2	1	1.38	FLG BOLT (3/4-NC X 2", GD8)
1	106-109	2	1	0.19	WASHER (.780")
1	106-469	2	1	0.00	FLG SCREW (M12-1.75 X 30MM)
1	106-470	1	1	0.00	FLG SCREW (M16-2.0 X 40MM)
1	106-709	6	1	0.00	FLG LK NUT (M12-1.75)
1	107-066	4	1	0.00	LOCKNUT (1-NC, GD8)
1	107-459	1	1	2.96	CABLE GUIDE BOLT
1	107-565	6	1	0.00	FLG LK SCREW (M12-1.75 X 40MM)
1	110-838	2	1	12.21	LONG CHAIN CLEVIS
1	115-003	1	1	0.00	ZERK (1/4-NF, STR)
1	115-012	2	1	0.00	ZERK (04N)
1	115-426	1	1	31.61	SEAT
1	117-412	1	1	1.62	ABRASION SLEEVE (1.00" X 34")
1	117-607	1	1	1.17	ABRASION SLEEVE (1.00" X 21")
1	117-713	1	1	3.05	ABRASION SLEEVE (1.00" X 76")
1	117-718	1	1	1.70	ABRASION SLEEVE (1" X 36")
1	117-993	1	1	1.19	ABRASION SLEEVE (1.00" X 23")
1	118-062	1	1	2.45	ABRASION SLEEVE (1.00" X 62")
1	125-177	2	1	3.08	COMPOSITION BUSHING (1.250")
1	125-444	2	1	2.71	THRUST WASHER (1.750")
1	125-571	6	1	2.39	FRICTION BEARING 1.25" X 1.0"
1	125-572	2	1	2.38	THRUST WASHER (1.50")
1	125-771	2	1	2.56	COMPOSITION BUSHING (1.25")
1	125-772	2	1	4.12	COMPOSITION BUSHING (1.5")
1	125-799	4	1	3.34	COMPOSITION BUSHING
1	149-059	1	1	546.85	HYDRAULIC CONTROL VALVE
1	151-038	2	1	72.29	CYL (2.0 X 1.0 X 4.0)
1	151-091	2	1	90.43	CYL (2.0 X 1.25 X 16.0)
1	151-208	1	1	359.10	CYL (2.5" X 1.5" X 5.77")
1	151-210	1	1	85.96	CYL (2" X 1.25" X 14")
1	154-220	12	1	0.69	CONNECTOR (04O-06S)
1	154-263	1	1	2.18	CONNECTOR (04S-04O45)
1	154-275	2	1	1.84	BK CONNECTOR (04O-04OBK)
1	154-278	1	1	0.59	CONNECTOR (04S-04O)
1	154-285	2	1	3.65	BK CONNECTOR (04O-04O45BK)
1	154-323	2	1	3.89	CONNECTOR (08S-10O90)
1	154-652	1	1	3.64	HOSE (04OFX-20"-3000)
1	154-668	1	1	4.64	HOSE (04OFX-32"-3000)
1	155-833	2	1	1.02	WIPER SEAL (1.500")
1	157-538	6	1	0.99	WIPER SEAL (1.250")
1	159-833	1	1	7.58	HOSE (04OFX45-73"-3000)
1	159-838	1	1	5.97	HOSE (04OFX45-33"-3000)
1	159-839	1	1	5.24	HOSE (04OFX-60"-3000)
1	170-419	2	1	8.23	LEAF CHAIN (#BL844, 13P)
1	178-223	1	1	8.67	TAPERED PIN (31.75MM X 138MM)
1	178-419	1	1	9.67	TAPERED PIN (38.1MM X 208MM)
1	178-420	1	1	8.73	TAPERED PIN (38.1MM X 178MM)
1	179-024	4	1	5.51	TAPERED PIN (25.4MM X 117MM)
1	179-209	1	1	14.10	TAPERED PIN (38.1MM X 320MM)
1	179-928	2	1	2.96	BUSHING (1.50" ID)
1	179-949	2	1	20.45	GRESABLE TAPRD PIN (1.25X6.85)
1	180-700	2	1	8.93	BUSHING
1	181-974	1	1	1.32	TAPERED INSERT (1.5")
1	181-981	4	1	1.04	TAPERED INSERT (1")
1	181-982	2	1	1.01	TAPERED INSERT (1.25")
1	183-863	3	1	6.13	TAPERED PIN (31.7MM X 128MM)
1	183-893	2	1	11.91	TAPERED PIN (1.250" X 6.250")

1	183-938	1	1	4.87	TAPERED PIN (31.7MM X 95MM)
1	190-889	2	1	59.14	SHOE KIT
1	301-641	1	1	38.68	35.5" BACKFILL BLADE PLATE
1	303-526	2	1	14.28	LINK
1	303-537	1	1	306.34	12" BUCKET
1	305-456	1	1	47.58	FORMED PLATE
1	305-457	2	1	3.69	END PLATE
1	305-581	1	1	41.94	SEAT MOUNT
1	307-359	1	1	144.13	A225 SWING POST
1	307-519	1	1	6.44	GUSSET
1	307-521	1	1	14.18	UPPER BRACKET
1	307-586	1	1	5.87	GUSSET
1	321-942	2	1	1.26	MOUNT PLATE
1	323-127	1	1	208.46	DIPPER
1	323-128	1	1	299.57	BOOM
1	324-557	1	1	56.10	PIVOT LINK
1	327-364	1	1	47.32	ATTACHMENT FRAME
1	365-478	2	1	2.66	LEVER (5.88")
1	499-022	2	1	5.79	LEVER (M12-1.75 X 200MM)
1	501-799	2	1	1.45	THRUST WASHER
1	501-895	8	1	0.60	THRUST WASHER
1	515-127	2	1	11.36	HOSE (10OFX-32"-3000)
1	515-735	1	1	5.25	HOSE (04OFX-22"-3000)
1	054-424	1	1	3.27	BACKHOE PARTS MANUAL

Appendix C – Component Drawings

Design of a Small Detachable Backhoe

Yen Kean Lee

David Crossley

Jacob Hamburger

Introduction

- **Design a small detachable backhoe for use on the SK500 Compact Utility machine for Ditch Witch**

Design Criteria

- **Must attach via Ditch Witch designed quick-attach plate**
- **Incorporate as many in-system parts as possible (proven parts)**
- **Allow machine hood to open**
- **Easily & quickly attachable**
- **Fit through a standard yard gate (36”)**

Product Research

- **Most patent research revealed all expired patents**
- **Market is currently saturated with models from several different manufacturers**

Current Design – BradCo

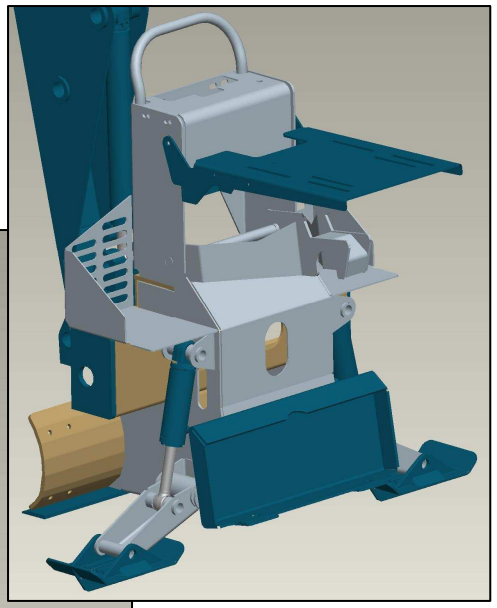
- **Current Issues**
  - Overall Width (42”)
  - Complex attach
  - Hood can’t open
  - Dry weight of 740 lbs. (incl. 12” bucket)

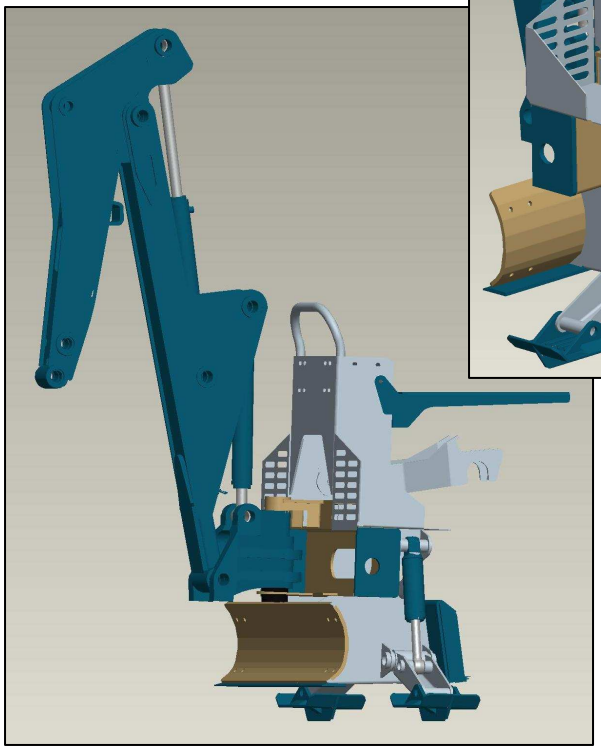
Final Design

- **Design Details**
  - Addition of stabilizers
  - Addition of backfill blade
  - Combination of existing components

"Various" Components

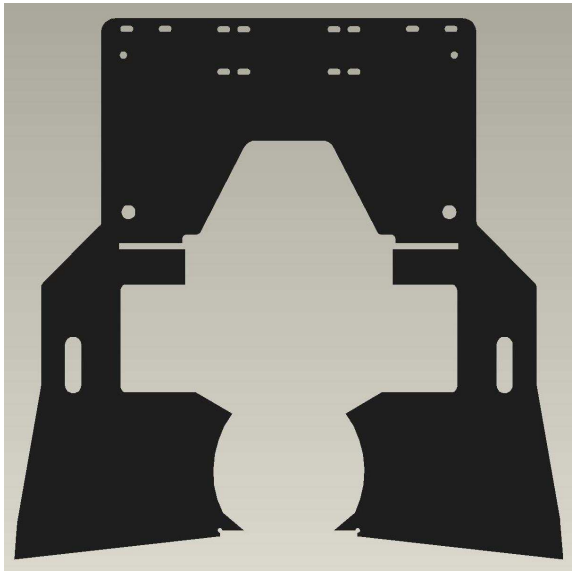
- **In system parts**
  Blue
- **Modified in system parts**
  Tan
- **Fabricated Parts**
  Gray





Frame

- Flame cut
- 3/16” steel
- Bent to accommodate cylinder housing
- Provides attach point for valve



Stabilizers

- **Outrigger style design**
- **Independent hydraulic controls**
- **Increases width by over 45%**
- **Eliminates side to side motion in loader arms & unit**

Tilt Lock

- **Prevents rotation of backhoe unit forward**
- **Provides brace for seat**
- **Slotted, drop-down design for easy hook up and removal**

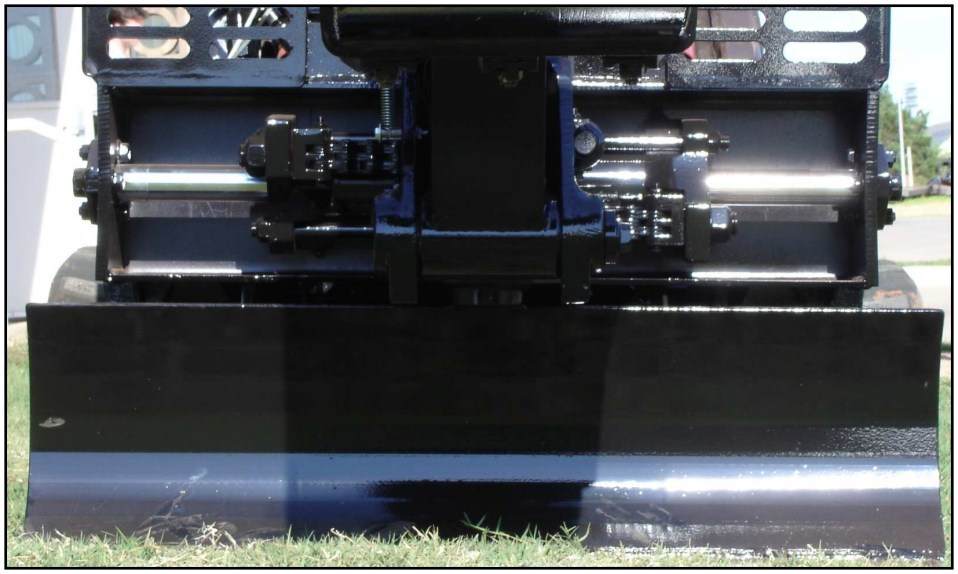
Backfill Blade

- Provides convenient means of refilling holes
- Adds support to frame and pivot
- Equipped with turf cutting edge

Backhoe Comparison

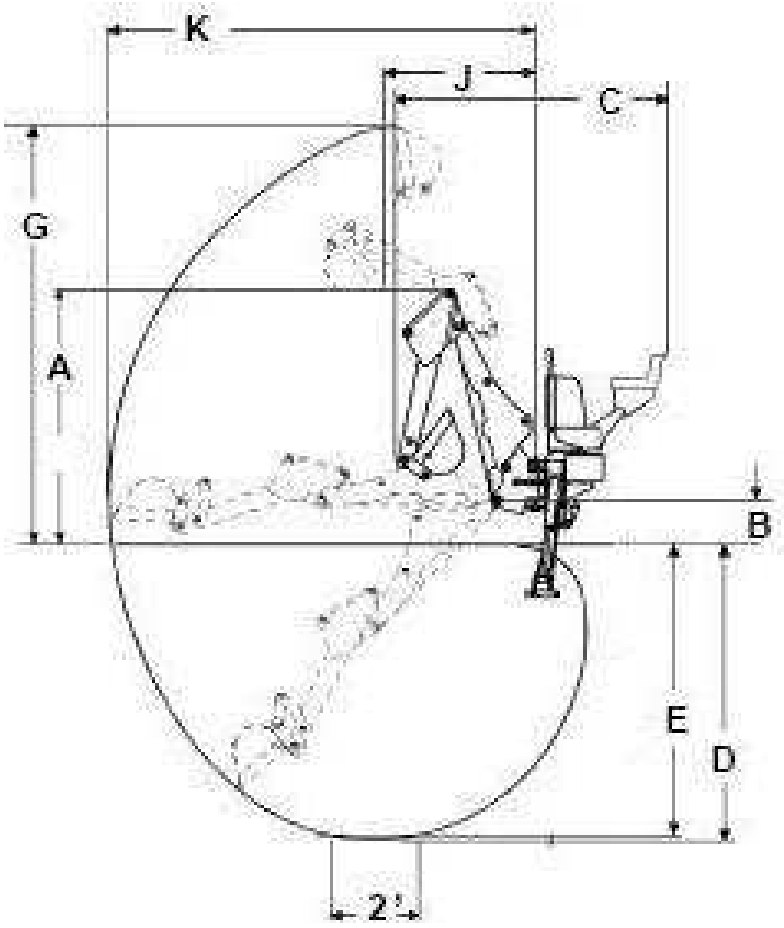
- **Ditch Witch**
  - Allows hood to open
  - Width = 35.5”
  - True quick attach
  - Weight = 840 lbs.
  - Digging depth (flat bottom) = 70”
  - Backfill blade
- **BradCo.**
  - Can’t open hood
  - Width = 42”
  - Inconvenient quick attach
  - Weight = 740 lbs.
  - Digging depth (flat bottom) = 76”
  - No backfill blade

Features



Specifications

A	75 in.
B	10 in.
C	60 in.
D	76 in.
E	70 in.
G	101 in.
J	40 in.
K	112 in.
Width – Transport	35 in.
Width – Operating	52 in.



Projected Budget

Total – Fabricated Parts	$204.54
Total – In system Parts	$3,162.75
Total – Assembly Labor	$649.80
TOTAL INITIAL COST	***$4,017.09***
Total – Component Replacement Savings	$414.00
TOTAL FINAL COST	***$3,603.09***
BradCo Final Cost	***$3,165.23***

Evaluation & Recommendations

- **Evaluation**
  - Good field test performance
  - Stabilizers improve controllability
  - Could be lighter
  - Overall, well sized for machine
  - No major failures!!!
- **Recommendations**
  - Component substitution
  - Custom made boom cylinder
  - Replace tapered pins

Future Production

Gantt Chart

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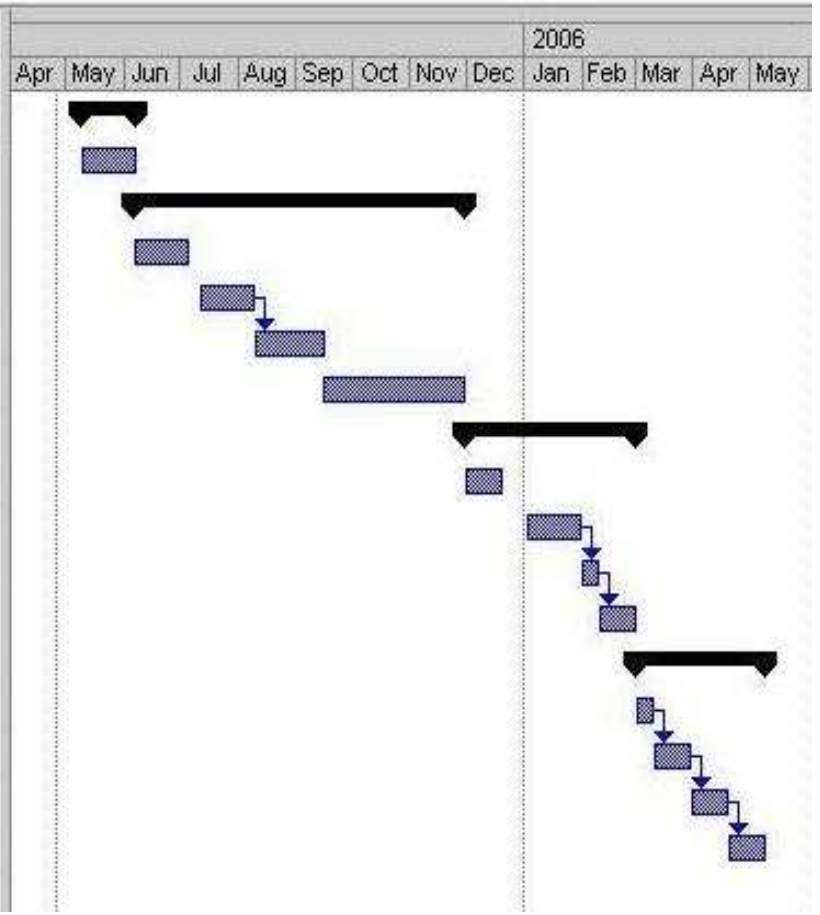


Acknowledgements

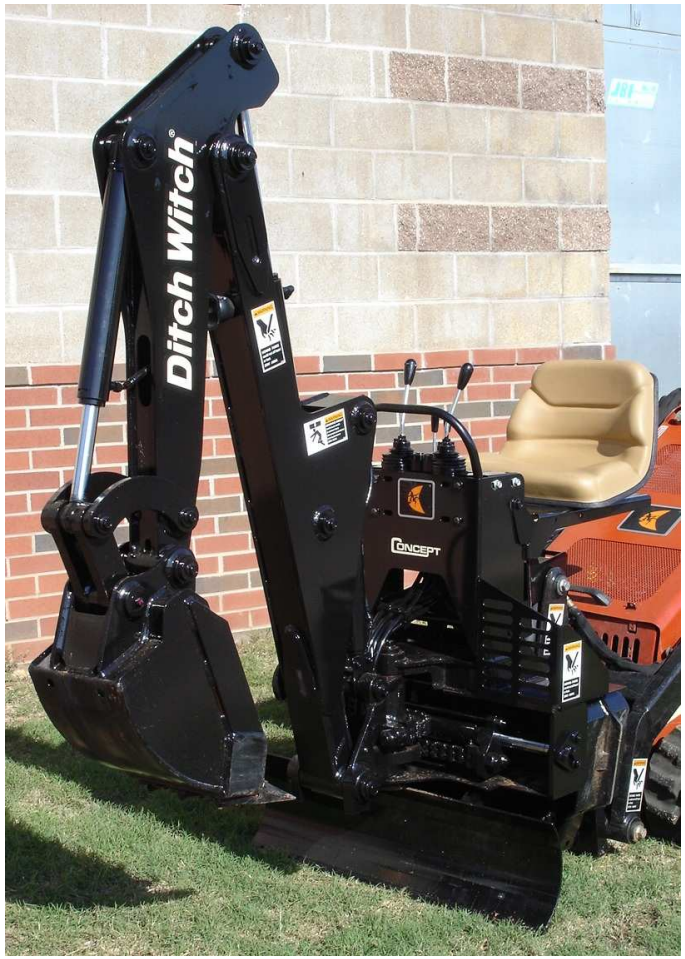
- **Engineering Specialties would like to thank the following for all their help:**
  - *Eddy Allen and all the engineers & staff at the Product Development Center for their guidance and assistance.*
  - *Special thanks to Dr. Paul Weckler, Mrs. Jana Moore, Mr. Wayne Kiner, and all BAE staff.*

Tighter!!!!

That's one small step…

For Ditch Witch; One giant leap

For the excavation industry!



Engineering Specialties

Fall Design Proposal
BAE Sr. Design 4012

David Crossley
Jacob Hamburger
Yen Kean Lee

Table of Contents

List of Illustrations

Introduction

Charles Machine Works, Inc. (CMW) is a manufacturing company that builds construction equipment in Perry, Oklahoma. Over the past 50 years, CMW has become synonymous with building the highest quality underground construction equipment in the world. They began in the late 1940s with a mechanical powered trencher that owner and founder Ed Malzahn's built in his father's machine shop.

Figure 1: Ed Malzahn and his revolutionary trencher.

This one machine has evolved into what the world now knows today as Ditch Witch. For the past 50 years, Ditch Witch has expanded its lineup to include horizontal boring machines, vibratory plows, and more recently, compact utility machines.

Ditch Witch is an industry leader in the trenching market, introducing the first mechanical trencher in 1949, and has continued to be on the forefront with the latest innovative technology ever since. Over the years, their product line has expanded to include various size trenchers as well as vibratory plows and backhoes for the units. In the late 1980s, they began to explore the budding horizontal boring industry and eventually produced an entire line of directional boring machines. In the most recent

years, Ditch Witch has decided to expand its lineup and branch out into the compact utility market.

The compact utility market segment has exploded in the last few years and is currently the fastest growing segment of the construction equipment industry. Ditch Witch manufactures multiple models that fall into this category. The vehicles have the capability of attaching over 70 different tools to the front, making these some of the most versatile machines on earth. Currently, this market produces annual net sales of approximately six billion dollars worldwide each year, making it an excellent venture for any company already involved in the construction industry. Unfortunately, several other companies, both large and small have began to manufacture similar machines and attachments, eager to get their own piece of this giant pie.

Problem Statement

Our team has been given the task of designing a small, detachable backhoe for the SK500 compact utility machine. Currently, Ditch Witch offers a backhoe for these machines, but it is purchased from another company. The purchased backhoe does not satisfy many of the design criteria desired by Ditch Witch. Therefore, Ditch Witch has decided it would be beneficial to their company if they were to design and build a backhoe of their own. This would allow them to offer some additional features as well as help to increase the overall profit margin on these machines. Consequently, our team was approached and given the task of designing the backhoe. The backhoe designed by our team will fit the SK500 compact utility machine and adhere to all of the design criteria set forth by Ditch Witch.

Statement of Work

For our design project, the team will be designing a small, detachable backhoe for a compact utility unit manufactured by Charles Machine Works, Inc. in Perry, Oklahoma. Charles Machine Works, or Ditch Witch, is one of the leading manufacturers of trenching and underground excavating equipment in the world. Over the past half decade, the compact utility market segment has grown into a six billion dollar worldwide market. Ditch Witch has released two hugely popular compact utility vehicles; the SK300 and the SK500. These small vehicles can utilize over 70 different attachments, making them possibly one of the most versatile tools to hit the jobsite in the last 30 years. Currently, many of the attachments for the SK's are purchased from outside vendors. However, Ditch Witch is now interested in producing more of these attachments "in house." This offers multiple benefits including the knowledge that the equipment they sell is completely compatible with their machines and an increased profit margin. One such attachment is the mini backhoe.

After meeting with the design engineers from Ditch Witch, the team was able to set forth some of the criteria this unit was expected to meet. First of all, it would have to attach to the SK500 unit via the quick-attach plate in the front of the machine. Our team would also have to make sure the overall width of the backhoe did not exceed 36 inches. In addition, it would also have to dig to a depth of at least 78 inches and have an overall weight no more than that of the current purchased unit (780 lbs.). The backhoe would need to incorporate some sort of mechanism to "lockout" the use of the tilt function on the attachment plate. Often times, users will rotate the attachment plate to reposition the backhoe to get a little bit deeper or larger hole. The problem with this

is it can become very unsafe for the user and make the machine unstable. The unit would be powered by the attachment hydraulic circuit on the machine, include safety kill switches, and have all wires and hoses easily disconnect at the mount plate. While accomplishing these things, it would also need to exceed the current model in some areas.

Some of the features required to exceed those of the present model include allowing the hood to open while the unit is attached as well as being easy and quick to disconnect (less than 5 minutes). There is also a desire for the machine to have some type of stabilizers to keep the SK balanced and steady during normal operation. Currently, the team is looking at multiple approaches to this problem and has yet to settle on any one way without further testing to confirm the solutions. Most conventional backhoes use a pair of pads that raise and lower hydraulically to keep the unit sturdy. However, one of the prototypes tested had a large blade mounted on the backhoe below the pivot post which doubled as both a brace to hold the machine and a backfill blade to fill in the hole once the digging is done.

Figure 2: Backfill blade built in to main frame of backhoe.

In addition, the backhoe would also be composed of as many “in-system” Ditch Witch parts as possible (cylinders, valves, bushings, etc…). This would not only make it easier to manufacture but cheaper as there would be no need for additional tooling. The design should also have a light kit included. Light kits have become much more commonplace on backhoes as they are used in residential areas or near streets where high visibility is imperative. Ditch Witch has also expressed the desire to explore the viability of additional technical features. These include an auxiliary hydraulic circuit at the end of the boom and a quick-attach plate for the bucket attach. With these features, the unit could become more versatile as the user would be able to change the tool on the end of the backhoe and hydraulically power that tool (such as a jackhammer) as well. Furthermore, our team is looking into the possibility of including other features that users might find useful on the backhoe, such as a thumb to aid in the handling of raw materials or debris.

Patent & Market Research

Patent Research

To begin our research into backhoe design, the team did preliminary research into backhoe and small digging attachments. One thing that was very apparent early on was the fact that many of the backhoe patents found were outdated. Most of the patents having to do with the backhoe design or design of the hydraulic systems were issued back in the 1960s and 1970s, making them obsolete. As the group began to search the internet, the absence of applicable patents became even more evident as the team found

several different manufacturers of both small and detachable backhoes for use on small tractors, compact utilities, and other machines.

Market Research

Market research revealed that there is a plethora of compact utility vehicles on the market. The biggest competitors in this segment are Toro and Bobcat. Toro is probably the predominant competitive machine in this class.

Figure 3: Toro Dingo compact utility unit.

Toro took advantage of its staggering presence in the lawn and garden market to introduce a handy utility machine for both home owners and landscapers. The machine features several different attachments, including a backhoe made by Toro. The biggest difference between the Toro and Ditch Witch machines is the use of rubber tires on the smaller Toros versus tracks on the SK. The backhoe currently offered by Toro is considered a light duty machine, with less potential in the more rugged construction industry. However, it provides a light and effective choice for customers needing to do small excavation jobs.

The Bobcat machine has similar roots to the SK. Bobcat has made a name for itself in the construction industry with its rugged line of skid loaders.

Figure 4: Bobcat compact utility loader with pallet fork attachment.

Like Ditch Witch, Bobcat has ventured into other markets including the compact utility segment. However, Bobcat does not currently offer a backhoe option with their compact utility machine (see Figure 4). However, consumers can still purchase aftermarket backhoes for the Bobcat machines.

Ditch Witch is looking to take advantage of its already established customer base in the small to mid-range construction equipment much like Toro and Bobcat did in their respective industries.

Engineering Specifications

Ditch Witch expressed a set of criteria the machine had to satisfy. Currently, Ditch Witch purchases a backhoe from another OEM vendor, BradCo. While robust and effective, the BradCo backhoe lacks many of the refinements and features Ditch Witch desired.

Figure 5: Ditch Witch SK500 with BradCo backhoe attachment.

Below is a list of specifications for the backhoe attachment set forth by Ditch Witch.

- Attach with the Ditch Witch quick couple on the SK 500.
- No wider than 36”.
- Incorporate some kind of stabilizing system.
- Use as many “in-system” components as possible.
- Lock on tilt.
- Must have a remote kill switch at operator’s seat. (Ditch Witch Standard)
- Dig a 6’ 6” deep hole. (SAE Standard)
- Include a light kit – desired
- Include an attachment tool valve at end of boom – desired
- Ability to open the hood fully on the SK 500 while backhoe is attached.

Design Concepts

The team has formed some feasible design concepts based on very limited amounts test knowledge. Due to an extremely wet weather pattern over the last few months, the team has only been able to get out and dig with the machines once. During that period, valuable insight was gained on how the prototypes work as well as what

features helped or hindered the digging process. Our team was unable to experiment and do any further testing with the machines to become more familiar with them and aid in our concept development.

During the testing, the machine's instability was noted immediately. Based on observations, this was a result of several aspects of the design. The first thing contributing to this was the size of the bucket on the machine. The prototype utilized a 12-inch bucket, which was later found to be somewhat excessive for this particular application. The larger bucket provided a much larger "grab area" as the bucket tried to dig into the soil. This larger area resulted in the machine being moved around excessively (see Figure 6).

Figure 6: Track skid marks left after digging with prototype machine.

Our team believes the use of a smaller bucket could greatly improve not only the stability of the machine, but also the overall performance. This prototype utilized the backfill blade in the front as its stabilizer. While the backfill blade is a nice addition to add to the overall versatility of the machine, it does not do a good job of securing the machine. This is even more evident when digging in already disturbed soil, as seen in Figure 6. It was concluded that a larger pad between the attachment frame and the

backfill blade would be very beneficial. This pad would not only serve to strengthen the design, it would more importantly provide a much more solid footing for the machine as it dug. Since the SK500 is not excessively heavy, no form of stabilizer can be expected to keep the machine completely anchored. However, our group feels the pad and blade combination would provide an adequate anchor without having to worry about greatly disturbing the soil.

Another area needing to be addressed in this design is the hydraulic control valve. While the valve used on the prototype was definitely adequate, our group feels the control characteristics could be improved to help bolster the overall efficiency of operation. The prototype had a reduction orifice in one of the ports. Unfortunately, the orifice was in the wrong port, and it became immediately evident how much this affected the handling characteristics of the machine.

Design Concept 1

The first design concept explored was similar to a design already incorporated at Ditch Witch on other, larger scale backhoes. To aid in their digging ability, Ditch Witch currently uses a compound arm on some of the larger machines. The setup actually moves the pivot point of the backhoe allowing the rotation of the backhoe to swing almost 270 degrees. The whole design will be scaled down greatly to fit the smaller version backhoe. The biggest advantage offered by this setup would be the ability to make the backhoe unit offset. In other words, the user would be able to move the pivot point of the backhoe across the front of the machine.

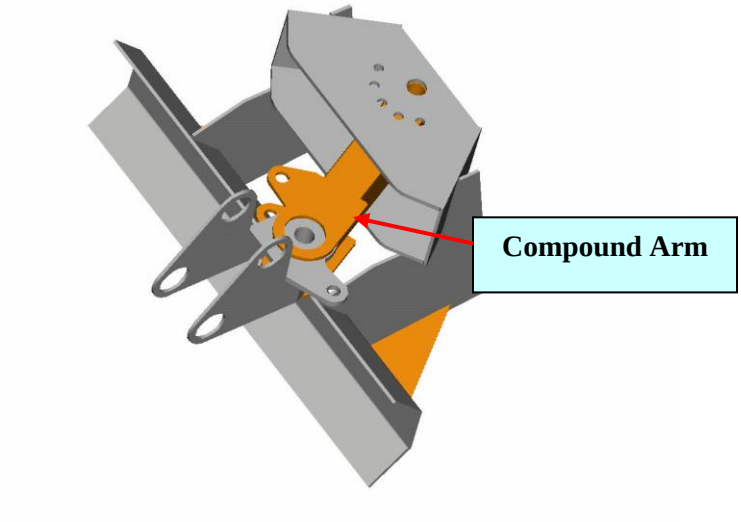


Figure 7: Top view of compound arm design.

This feature would be especially useful in residential or small areas that require the machine to dig next to some obstacle, such as a fence or structure. In addition, many of the components needed to construct such a design are already in system parts.

With the compound arm setup, the overall center of gravity of the machine would be shifted out in front of the main backhoe frame. Therefore, the machine would tend to be a bit more front heavy. However, this will increase down force on the stabilizers, making the machine more stable and much safer.

Design Concept 2

The second design concept is also used in several applications at Ditch Witch on larger scale backhoes. This setup incorporates a single, double-ended cylinder. Using the cylinder and chain links, the cylinder is the mechanism used to rotate the boom of the backhoe (see Figure 8).

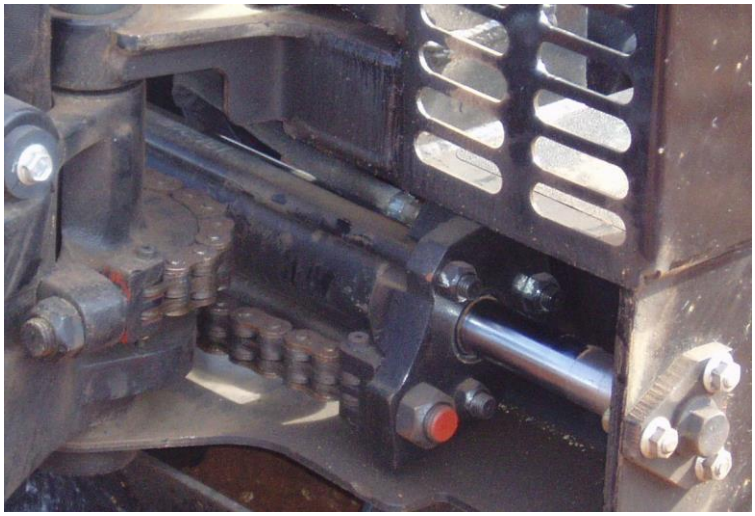


Figure 8: Double-ended cylinder and chain rotation system.

The setup is very compact and effective at rotating the boom in a very confined space. However, the double-ended cylinder is rather expensive and there have been some concerns with chain tension in the past. Also, with this setup the pivot is stationary and cannot be offset as in the previous design. One issue has been maintaining the proper tension on the chains. On some of the larger model backhoes, Ditch Witch has encountered problems with slack in the chain at different points in the rotation. The reason for this is the radius of the pivot is not constant. The pivot is a cast part and at times, keeping the dimensions exact can be a challenge. On larger models, a small percent change in dimensions can result in big changes in the radius resulting in slack in the chains. Often times, users will try to tighten the chain to take out the slack and end up over-stretching the chain as it runs through the full turn arc. Fortunately, this small backhoe requires a much smaller pivot, making manufacturing tolerances better. As a result, this problem becomes much more insignificant.

The booms will also be redesigned to lighten the overall weight of the machine. The overall geometry and location of pivot and hinge points will remain close to the same, keeping the dig depths and overall functionality of the machine as close as possible to the other prototypes.

The main frame will be the same as the one used on the prototype machines. Not only does this frame already mate well to the pivot and backfill blade, it is also meets the 36-inch width specification.

Design Concept 3

The third concept is a slightly modified version of a prototype already built by Ditch Witch. The design would be a slight modification of the first tested prototype (see Figure 9).

Figure 9: First prototype tested at Ditch Witch.

The design would include the revised stabilizing pad as well as a smaller bucket for improved performance. The biggest advantage offered by this design is the fact that all of the parts are already manufactured for some machine at Ditch Witch. Therefore, no additional parts would need to be made. Instead, parts can be easily taken from other products to assemble this machine. However, the boom and dipper arms on this prototype are considerably overbuilt for this machine. The result is an overall weight of nearly 780 pounds.

The reason our team chose to include this as one of the design concepts lies within the ideology of Ditch Witch's company. At Ditch Witch, innovation and

ingenuity are always encouraged to help make the company the best it possibly can be. However, the company also lives by the motto of, “We don’t need to reinvent the wheel.” In other words, Ditch Witch is also very open to using ideas or concepts they have come up with in the past that can still provide an edge in the future. The backhoe prototype, in Figure 10, developed by CMW is a very competitive machine when compared with the BradCo. It also satisfies many of the engineering specifications set forth by Ditch Witch. Unfortunately, it does fall short of the design requirements in a few areas. Our group believes that with a few modifications, it could be a very competitive machine.

Figure 10: Ditch Witch Prototype 1 small detachable backhoe.

Additional Design Concepts

Each of these designs offers advantages and disadvantages. The best solution results in a machine that is lightweight but rugged and performs at the level for which Ditch Witch machinery is known. Each design satisfies all of the engineering

specifications set forth by Ditch Witch for this project. Currently, our team would utilize the in-system frame that was used on the first prototype. This frame not only provides a structurally sound base, but includes the necessary features such as the seat and tilt prevention mechanism.

Proposed Budget

For this project, our group has yet to formulate an exact and precise budget. Without being sure which concept Ditch Witch will chose to pursue as well as which features CMW will want to include, our team has yet to finalize any kind of project budget. Below (Figure 11) is a general budget for the testing and construction of concepts.

	In-system Costs	Estimated Costs
Hydraulic Components	$1130	$1130
Frame	$540	$540
Boom & Dipper Arms	$515	$475
Bucket	$260	$170
Misc. (Pins, bushings, etc…)	$380	$355
Total	$2825	$2670

Figure 11: Proposed budget for constructions and development of concepts.

The table above is divided into two different columns. The first column represents costs of in-system components that are currently used or will be used in the development. The

second column is a list of estimated costs. Using the prices of in-system parts, our group has estimated what it will cost to build a concept unit. The reason costs were used from in-system parts is because our team is not yet sure which design Ditch Witch will choose to pursue.

Conclusion

Currently, our group has submitted three designs for Ditch Witch to select from. Once a selection is made, a fully detailed model will be drafted. From there, our group will begin to construct the concept, testing ideas along the way and making the necessary corrections. Attached in Appendix A, a Gantt chart can be seen showing the schedule for the project through the spring semester. Our team looks forward to continuing this project next semester with Charles Machine Works, Inc.

Appendix A – Gantt Chart

Design of a Small Detachable Backhoe

Submitted to:

Charles Machine Works

Yen Kean Lee

David Crossley

Jacob Hamburger

Engineering Specialties

Ditch Witch GROUNDBREAKING

STATE

Introduction

- **Design a small detachable backhoe for use on the SK500 Compact Utility machine**

Problem Definition

- **Explore use of in-system components**
- **Perform as well as or better than competitive machines**
- **Uphold legacy of Ditch Witch quality**
- **Look at implementation of additional design features**

Client Background

- **Founded in Perry, OK in the late 1940s by Ed Malzahn**
- **Trenchers, Vibratory Plows, Horizontal Directional Drilling, Electronics**
- **Latest venture – Compact Utility**

Design Criteria

- **Must work with SK500 quick-attach plate**
- **Incorporate as many in-system parts as possible**
- **Allow machine hood to open**
- **Easily Attachable**
- **Fit through a standard yard gate (36”)**

Current Design

- **Current Issues**
  - Overall Width
  - Complex attach
  - Hood can't open
  - Dry weight of 740 lbs. (incl. 12" bucket)

Engineering Specifications

- **Dig 6’ 6” hole with 2’ flat bottom (ATI)**
- **Weigh <700 lbs.**
- **Operate off 8 gpm flow**
- **Less than 36” wide**

Engineering Specifications

- **Must prevent tilt on attach plate**
- **Remote kill switch on the operators seat**

Patent Research

- **Most patent research revealed all expired patents**
- **Market is currently saturated with models from several different manufacturers**

Market Research

- **Toro**
  - Manufactures small lawn, garden, and landscape equipment
  - Currently offers backhoe as an option with Dingo compact utility

Engineering Specialties

Ditch Witch GROUNDBREAKING

STATE

Market Research

- **Other Competitors**
  - Kanga
  - Power-Trac
  - Bobcat*

*Doesn't currently offer backhoe with compact utility

Field Testing

- **Tested two Ditch Witch prototype machines on SK500s**

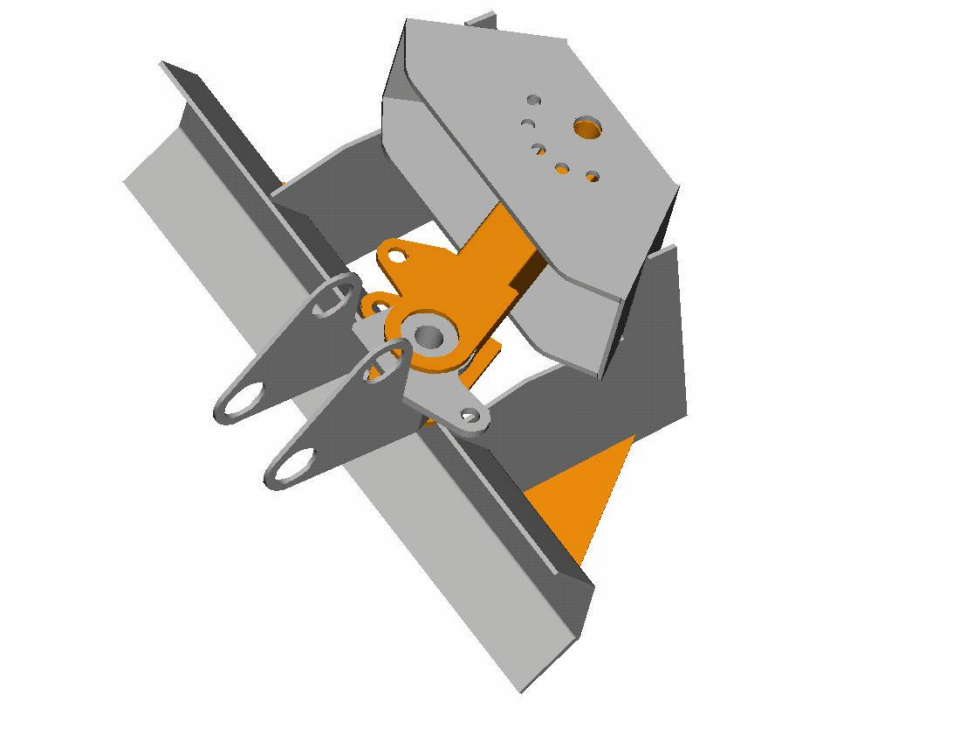
- **Monsoon season**
  + Digging in dirt

  Limited Field Testing

Ditch Witch GROUNDBREAKING

Proposed Design 1

- **Compound Arm Design**
  - Similar in to design presently used on XT850
  - Allows pivot of backhoe to achieve offset position



Proposed Design 1

- **Pros**
  - Offset pivot
  - Uses existing design from current Ditch Witch backhoe
  - Incorporates backfill blade
- **Cons**
  - Complicated
  - Slight redesign of compound arm to fit smaller area
  - Heavy
  - Slightly more expensive

Proposed Design 2

- **Single, double ended cylinder with chain links**
  - Same design used in several different size CMW backhoes currently

Proposed Design 2

- **Pros**
  - Uses many in-system parts including pivot
  - Very compact design
  - Effective and efficient design
- **Cons**
  - Expensive cylinder
  - Chain tension issues
  - No offset pivot

Proposed Design 3

- **Modification of current prototype**
  - Addition of stabilizer pad
  - Fine tuning of hydraulic valve

Proposed Design 3

- **Pros**
  - Uses all in-system components
  - Rugged effective design
  - Workable design
- **Cons**
  - Heavy
  - Too large for machine to effectively handle
  - No offset

Other Design Considerations

- **Additional Features**
  - Stabilizers
  - Backfill blade
  - Remote kill switch
  - Quick disconnect hydraulic couplers
- **Options**
  - Light Kit
  - Auxiliary Kit
  - Adjustable Swing Speed
  - Attachable thumb

Project Budget

	In-System	Estimated
Hydraulic Components	$1130	$1245
Frame	$540	$540
Boom & Dipper Arms	$515	$475
Bucket	$260	$170
Misc.	$380	$355
Total	**$2825**	**$2785**

Conclusion

- **More field testing will need to occur**
- **Experiment with different size buckets**
- **Redesign boom lighter for better overall performance**
- **Redesign stabilizers for improved effectiveness**

Spring Schedule

- **More field testing**
- **Final concept development**
- **Finish component drafting**
- **Build prototype**
- **Field test with prototype**
- **Final Design**

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  - Eddy Allen, Joe Worlow, Joe Greenlee, Kelvin Self, & Cody Sewell
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